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Editors

Accelerator Physics at the Tevatron Collider

Springer

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We dedicate this book to Fermilab staff, who made possible the Tevatron—the particle accelerator which shaped the world high energy physics for more than quarter of century.

Preface

The intent of this book is to present major advances in accelerator physics and technology implemented at the Tevatron proton–antiproton collider at the Fermi National Accelerator Laboratory in Batavia, IL, USA, during its quarter of century long quest for better and better performance. The collider was arguably one of the most complex research instruments ever to reach the operation stage and is widely recognized for many technological breakthroughs and numerous physics discoveries. In this book we have tried to coherently describe the contributions to the physics of colliding beams made at the Tevatron. Both theoretical and experimental works are presented in uniform fashion. Throughout the text, we use the same symbol definitions and provide references which are readily available for the reader. For example, all the references to the proceedings of the International, European and IEEE Particle Accelerator Conference series (PACs) can be found at the JACOW website http://accelconf.web.cern.ch/accelconf/. All cited Fermilab technical publications are available at *inSPIRES* http://inspirehep.net/.

In Chap. 1 we outline the basics of the colliding beams technique and brief history of the Tevatron, describe the Fermilab accelerator complex, and overview the collider luminosity progress. Other chapters are devoted to special topics, such as beam optics methods used in the Tevatron accelerators (Chap. 2), accelerator magnets and magnetic field effects on beam dynamics (Chap. 3), novel longitudinal beam manipulation methods widely used at the Tevatron (Chap. 4), high intensity beam issues and instabilities (Chap. 5), beam emittance growth and halo collimation (Chap. 6), production and cooling of the antiprotons (Chap. 7), the beam–beam effects (Chap. 8), and beam instrumentation (Chap. 9).

Batavia, IL

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Symbols

Symbol(s)	Meaning	Units
L	Luminosity per IP	$cm^{-2}\ s^{-1}$
$I_L = \int L\ dt$	Integrated luminosity	pb^{-1}/week, fb^{-1}
$E_{p,a}$	Proton(antiproton) beam energy	GeV
C, $R = C/2\pi$	Ring circumference, radius	m
$c = 2.9979 \times 10^8$ m/s, v $\beta = v/c$; $\gamma_{p,a} = (1-\beta^2{}_{p,a})^{-1/2}$	Speed of light, velocity, relativistic factors (protons, antiprotons)	
$f_0 = C/v$, f_{RF}, $h = f_{RF}/f_0$	Revolution frequency, RF frequency, harmonics number	MHz
x, y, z, s	Horizontal, vertical, and longitudinal displacements, longitudinal coordinate	
$Q_{x,y,s}$	Horizontal, vertical, synchrotron tune	
N_b	Number of bunches	
t_b	Bunch spacing	ns
$N_{p,a}$	Protons (antiprotons)/bunch	10^9
$\varepsilon_{(p,a)\ (x,y,L)}$	RMS normalized emittance (proton, antiproton), (horizontal, vertical, longitudinal)	π μm, eV s
$\sigma_{(p,a)(x,y,z)}$	RMS beam size (proton, antiproton), (horizontal, vertical, longitudinal)	μm, m
$\sigma_{E,\delta}$	RMS energy spread, relative energy spread	
$\beta_{x,y}$, $\alpha_{x,y}$, $D_{x,y}$, $\beta^*{}_{x,y}$	Beta- and alpha-beam optics functions (horizontal, vertical), dispersion, beta-function at IP	m, cm
$x,y,z = (2J_{x,y,z}\beta_{x,y,z})^{1/2}\ cos(\psi_{x,y,z})$	Coordinates, actions, variables, and phases	
V_{RF}	RF voltage amplitude	MV

(continued)

Symbol(s)	Meaning	Units
$Z_{\parallel}, Z_{\perp}, Z_0$	Longitudinal, transverse impedance, free space impedance	Ohm, Ohm/m, 377 Ω
$H(\sigma_z, \beta^*, \ldots)$	Hour-glass factor	
$e = 2.71828 \ldots$		
$e = 1.602 \times 10^{-19}$ C	Electron charge	
$m_{\mathrm{p}} = 938.27$ MeV/c^2	Proton mass	
$m_{\mathrm{e}} = 511$ keV/c^2	Electron mass	
$r_p = e^2/m_p c^2 = 1.535 \times 10^{-18}$ m	Proton classical radius	
$r_e = e^2/m_e c^2 = 2.818 \times 10^{-15}$ m	Electron classical radius	

Abbreviations

AA	Antiproton Accumulator at Fermilab
ANL	Argonne National Laboratory, USA
BNL	Brookhaven National Laboratory, USA
BPM	Beam position monitor
CERN	European Organization for Nuclear Research, Switzerland
DESY	Deutsches Elektronen-Synchrotron Laboratory, Germany
FNAL	Fermi National Accelerator Laboratory, USA
Fermilab	Fermi National Accelerator Laboratory, USA
HERA	Hadron-Elektron Ring-Anlage at DESY
IP	Interaction point
ISR	Intersection Storage Ring at CERN
LHC	Large Hadron Collider at CERN
Linac	Linear accelerator
MI	Main Injector synchrotron at FNAL
Quad	Quadrupole magnet
RR	Recycler Ring at FNAL
Sp(p)S	Super Proton (antiproton) Synchrotron at CERN
SSC	Superconducting Super Collider, USA
Tevatron	TeV proton antiproton collider at Fermilab

Parameters of Fermilab Accelerators

		BS	MI	RR	DB	AA	TeV	
Particles		*p*	*p*, *pbar*	*pbar*	*pbar*	*pbar*	*p*, *pbar*	
Circumference	C	474	3,319	3,319	505	474	6,283	m
Injection energy (kinetic)	E_{inj}	0.4	8	8	8	8	150	GeV
Peak energy (kinetic)	E	8	150	8	8	8	980	GeV
Cycle time		1/15	2.2	-	2.2	-	ramp 84	s
Harmonic number	h	84	588	-	90	84	1,113	
Transition gamma	γ_{t}	5.5	21.6	20.7	7.7	6.2	18.6	
Maximum RF voltage	V_{RF}	0.75	4.0	0.002	5.1	0.04	1.4	MV
$\beta_{\max}$ in cells		34/20 (h/v)	57	55	16	52/40	100	m
β^* at collision points		–	–	–	–	–	0.28	m
Maximum dispersion	D_x	3.2	2.2	2	2.1	9	8	m
Tune (approx.)	$Q_{x,y}$	6.7	22.42	25.45/ 24.46	9.76/ 9.78	6.68/ 8.68	20.59	
Bend magnet length		2.9	6.1/4.1	4.3/2.8	1.6	1.5/3/4.6	6.1	m
Half-cell length		19.76	17.3	17.3	4.4		29.7	m
Bend magnets/ cell		4	4	4	2		8	
Bend magnets total		96	300	344	66	24	774	
Phase advance per cell		96	90	79/87 (v/h)	60		68	°
Cell type		FOFDOOD	FODO	FODO	FODO		FODO	

BS booster, *MI* main injector, *DB* debuncher, *AA* antiproton accelerator, *RR* recycler, *TeV* tevatron, *p* protons, *pbar* antiprotons

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